Civil and Environmental Research
ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online)
Vol 3, No.1, 2013
www.iiste.org

Effect of Admixture on Fire Resistance of Ordinary Portland Cement Concrete

Aka Adefemi [1,]*; Usman Muhammad [2]; Umar Muhammad Birnin Kebbi[2] & Samuel Olugbenga[3]

1. Department Of Building, Federal University of Technology, P.M.B. 65, Minna, Niger State Nigeria.
2. Department of Quantity Surveying, Waziri Umaru Federal Polytechnic P.M.B. 1033, Birnin Kebbi Kebbi State Nigeria.
3 Department of Urban Regional Planning, Waziri Umaru Federal Polytechnic P.M.B. 1033, Birnin Kebbi Kebbi State Nigeria. (* E-mail of the corresponding author: akafemi@yahoo.com)

Abstract

Ordinary Portland Cement (OPC) Concrete deteriorates considerably when exposed to aggressive environment such as fire or elevated temperatures. The addition of certain materials obtained from agricultural and industrial wastes to OPC concrete could improve its performance in this environment. This paper investigated the effect of Carbide Waste (CW) on the compressive strength of concrete when exposed to fire. This was achieved by partially replacing OPC with 5, 10, 15 and 20 percent (%) of CW to produce 150 x 150 x 150mm concrete cubes. Sample of 100% OPC were also produced and served as the control. The quantities of cement, fine aggregate and coarse aggregate used for the production of concrete specimens were obtained through absolute volume method of mix design. Water/cement (w/c) ratio of 0.65 was adopted for OPC/CW concrete and the control. For the purpose of the research, Ninety (90) concrete cubes were produced for the two specimens. The specimens produced were cured in ordinary water for 28 days after which they were heated in a furnace at varying temperatures of 200, 300, 400, 600, and 800^{o}C. Specimens were heated for 2 hours at each testing temperature to achieve the thermal steady state after which their compressive strengths were determined. Increase in compressive strength was observed in the control specimen up to 300^{o}C after which the specimen suffered severe loss with further increase in temperatures up to 800^{o}C. However, the compressive strength of CW concretes increases with increase in temperature up to 500^{o}C and then, decreases with further increase in temperatures. 10% replacement of OPC with CW performs satisfactorily better than other replacement level at all temperatures. Replacement of OPC by 10% CW increases concrete resistance to fire by 14% of OPC concrete.

Keywords: Blended Cement, Carbide, Concrete, Fire and Performance.

1 Introduction

Concrete is a construction material composed of Portland cement and water combined with sand, gravel, crushed stone, or other inert material such as expanded slag or vermiculite. The major constituent of concrete is aggregate which may be natural (gravel or crushed rock with sand) or artificial (blast furnace slag, broken brick and steel shot). Another constituent is binder which serves to hold together the particles of aggregate to form concrete. Commonly used binder is the product of hydration of cement, which is the chemical reaction between cement and water (Neville and Brooks, 2002). Admixture may also be added to change some of the concrete properties. CW in this study is the admixtures.

According to Arioz (2007), admixtures are ingredients other than water, aggregates, hydraulic cement, and fibers that are added to the concrete batch immediately before or during mixing. A proper use of admixtures offers certain beneficial effects to concrete, including improved quality, acceleration or retardation of setting time, enhanced frost and sulfate resistance, control of strength development, improved workability, and enhanced finish ability. It is estimated that 80% of concrete produced in North America these days contains one or more types of admixtures. According to a survey by the National Ready Mix Concrete Association, 39% of all ready-mixed concrete producers use fly ash, and at least 70% of produced concrete contains a water-reducer admixture. Admixtures vary widely in chemical composition, and many perform more than one function. Two basic types of admixtures are available: chemical and mineral.

Chemical admixtures are materials that are added to the constituents of a concrete mixture, in most cases, specified as a volume in relation to the mass of the cement or total cementitious materials. The admixtures interact with the hydrating cementitious system by physical and chemical actions, modifying one or more of the properties of concrete in the fresh and/or hardened states. ASTM C 414 stated that chemical admixtures are used to enhance the properties of concrete and mortar in the plastic and hardened state. These properties may be modified to increase compressive and flexural strength at all ages, decrease permeability and improve durability, inhibit corrosion, reduce shrinkage, accelerate or retard initial set, increase slump and workability, improve pump ability and finish ability, increase cement efficiency, and improve the economy of the mixture.

Concrete containing mineral admixtures is used extensively throughout the world for good performance, ecological and economic reason. The most common cementitious materials that are used as concrete constituents, in addition to Portland cement, are fly ash ground granulated blast furnace slag, silica fume and rice husk ash. They save energy, conserve resources and have many technical benefits (Arioz, 2007). Metakaolin is a recent addition in the list of pozzolanic materials. All admixtures to be used in concrete construction should meet specifications; tests should be made to evaluate how the admixture will affect the properties of the concrete to be made with the specified job materials, under the anticipated ambient conditions, and by the anticipated construction procedures ASTM C 414.

Concrete is well known for its capacity to endure high temperatures and fires, owing to its low thermal conductivity and high specific heat (Arioz 2007). However, it does not mean that fire as well as higher temperatures does not affect the concrete. Characteristics such as color, compressive strength, elasticity, concrete density and surface appearance are affected by high temperature Morsy et al. (2009) therefore; improving concrete's fire resistance is a field of interest for many researchers lately. According to past studies, it is possible to improve fire resistance of concrete in few ways. Cement replacement with pozzolanic materials is one of the very efficient methods (Demirboga 2007). The addition of polypropylene fibers in a concrete mix is also found to be useful Xiaoa (2006). However, the main attribution to thermal properties of concrete is provided by aggregates Savva (2005). Fire resistance of concrete is highly dependent on its constituent materials, particularly the pozzolans. The effect of fire or high temperature on concrete containing Carbide Waste (CW) has not been fully investigated.

CW is the remnant of oxy-acetylene gas used in welding industries to join pieces of metal by road side panel beaters and it is whitish in color. The whitish color material which was regarded as waste and ordinarily posed environmental nuisance in terms of its unpleasant and unsightly appearance in open-dump sites located at strategic places within the societies can now be considered as binder in partial replacement for expensive, unaffordable or unavailable cement if dried in the sun in an open field for a period of one week, grinded and then sieved to cement fineness. Dauda, (2006) investigated the strength properties of concrete using CW as partial replacement of OPC and observed that the compressive strength of concrete increased in CW content of an amount up to 10% replacement and decreased with further percentage increase. Abalaka (2007) investigated the performance of bricks stabilized with CW and observed appreciable increase in compressive strength of the bricks over the control (bricks stabilized with other form of waste materials). The partial replacement of OPC with CW in concrete production should be a welcome development in Nigeria considering its major benefits in the area of cost reduction in rural construction, increase manufacturing activities, improve concrete performance and reduce the need for imported materials. The cost of CW/OPC concrete is very low compared to that of OPC concrete but there is need to ascertain the performance of the concrete when exposed to aggressive environment such as fire or elevated temperatures since human safety in case of fire is one of the major considerations in the design of buildings, it is extremely necessary to have a complete knowledge about the behavior of all construction materials before using them as structural elements.

Neville and Brooks (2002) opined that the effect of increase in temperature on the strength of concrete is not much up to a temperature of about 250^{o}C but above 300^{o}C, definite loss of strength takes place and that hydrated hardened concrete contains a considerable proportion of free calcium hydroxide ($Ca(OH)_2$) which loses its water above 400^{o}C leaving calcium oxide (CaO). If this CaO gets wet or is exposed to moist air, rehydrates to $Ca(OH)_2$ accompanied by an expansion in volume. This expansion disrupts the concrete.

Researchers and investigators differ in their opinion regarding the changes in the properties of concretes, particularly in the range of 100– 300 ^{o}C whereas for temperature above 300 ^{o}C, there is uniformity in opinion concerning a decrease in mechanical characteristics (Piga 1995). However, strength reductions which have been reported in the literature reveal significant quantitative differences due to the variety of high temperature condition tested, and the variety of constituent materials of concrete used. It is recognized that the behavior of concrete subjected to high temperatures is a result of many factors such as heating rate, peak temperatures, dehydration of C–S–H gel, phase transformations, and thermal incompatibility between aggregates and cement paste (Foldvari 1997).

According to Tan (2012), OPC specimens heated to 400 °C or above have been shown to exhibit severe cracking to the point of disintegration after a few days. However, it was found that concrete made with blends of 35%, 50% and 65% Slag performed much better. In the Slag specimens there was no visible cracking after exposure to the higher temperatures. Furthermore, The concrete with 100% OPC degraded to powder over the year, while the concrete made with Slag maintained its strength over the same period.

In the light of the above, this paper focused essentially on the compressive strength of concrete made with CW as partial replacement of cement if exposed to fire or elevated temperatures.

2 Materials and Methods

The Research was carried out in building laboratory of Ahmodu Bello University Zaria Nigeria. CW used for the research was obtained from road side panel beaters within Zaria Local Government Area of Kaduna State. CW was grinded by grinding machine and then sieved with 75µm BS sieve. Only those that passed through 75µm sieve were used for the research. Dangote brand of Ordinary Portland Cement (OPC) was used. The cement was defined according to the Nigerian Industrial Standard (NIS) as NIS 444: 2003 CEM II A- L32.5R., naturally occurring clean sharp river sand and coarse aggregate obtained from a small quarry along Samaru-PZ near school of Aviation Technology Zaria, sieved with 10 mm and 20 mm sieve sizes to get rid of the suspended and organic impurities were used for the research.

Physical property of CW was determined to confirm its suitability as partial replacement of cement in concrete production. Properties such as specific gravity, bulk density, moisture content and absorption capacity of CW and sand were investigated. The specific gravity of CW and sand was determined in the Laboratory in accordance with the requirement of ASTM C 127 – 93. The compacted and un compacted bulk density of the materials was determined by the method recommended by BS 812: Part 2 (1975). The moisture content and absorption capacity test of CW and sand was determined in accordance to BS 1377: Part 2 (1975).

To assess the suitability of CW as partial replacement of OPC in concrete production, Seventy five (75) trial mix with absolute volume method of mix design in ratio 1:2:4 was first carried out at varying percentage (%) replacement level of 0, 5, 10, 15 and 20% of OPC for CW at different water/cement (w/c) ratio varying from 0.5 to 0.7. They were immersed in ordinary water for 28 days and crushed to determine their compressive strength. The essence of this was to determine the appropriate w/c ratio that would give the highest strength in concrete which was finally adopted for the research. The 0% specimen served as the control. Water/cement ratio of 0.65 which gives the highest compressive strength at the trial mix stage was finally adopted for the production of the final specimens. Ninety (90) concrete specimens were prepared and used for the actual research. The specimens were cured in ordinary water for 28 days after which they were heated in a furnace at varying temperatures of 200, 300, 400, 500, 600 and 800^{o}C. Specimens were heated for 2 hours at each testing temperature to achieve the thermal steady state after which their compressive strengths were determined. The preparation of the test specimens follows the procedure as outlined by appropriate British Standards especially BS 1881: 124 (1988) and BS 1881: 125 (1986). In the process of the research, standard test such as soundness, workability and setting time were also carried out.

3 Results and Discussion

3.1 Physical Properties of Materials

Table 1 shows the results of physical properties of the materials used for the research. From the results, the specific gravity of CW was observed to be 2.35. The value obtained complies with BS 812:1991 specification for Powdered Burnt Bricks (PBB) which specified its range to be minimum of 2.20 and maximum of 2.80. The specific gravity of CW is also within the range of 1.9 to 2.4 recommended for pulverized fuel ash (Neville and Brooks, 2002) and also similar to the values reported by Dashan and Kamang (1999); Oyetola and Abdullahi (2006) on Acha Husk Ash

(AHA) and RHA which was 2.12 for AHA and 2.13 for RHA. The specific gravity of sand was found to be 2.65. The value obtained falls within the limit for natural aggregates which ranges from 2.6 to 2.7 (Neville and Brooks, 2002).

The compacted bulk density of CW was observed to be1110 kg/m^3. The value obtained is close to 1115 k/m^3 reported by Taylor (1991) on PBB. In comparison, the bulk density of CW is less than the bulk density of OPC (1440kg/m^3), this means that CW is a lightweight material. The compacted bulk density of sand was found to be 1600kg/m^3. This value is very close to the range given for bulk density before excavation of sandy soils which ranges from 1650 Kg/m3 to 1850kg/m3(BS812:2 (1975)).

Table 1: Results of Physical Properties of OPC, CW and Sand

Properties	**Sample Type and Description**		
	CW	**Sand**	**OPC**
Specific Gravity	2.35	2.65	3.15
Compacted Bulk Density (kg/m^3)	670	1600	1440
Un compacted Bulk Density (kg/m^3)	540	1490	1270
Absorption Capacity (%)	27.55	-	-
Moisture Content (%)	2.04	-	-

3.2 Chemical Properties of Materials

From the result of chemical analysis, the CW used in the study does not satisfy the requirement of ASTM C 618-1978 for Pozzolanas, since the summation of the percentage composition of silica oxide (SiO_2), Aluminium Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3), is 28.82% which is very less than 70% specified by the code.

Table 2: Chemical Analysis of CW and OPC

Constituents	CW (%)	OPC (%)
Calcium Oxide (CaO)	64.79	72.70
Silica Oxide (SiO_2)	20.93	11.00
Aluminium Oxide (Al_2O_3)	4.40	3.20
Ferrous Oxide (Fe_2O_3)	3.49	3.87
Magnesium Oxide (MgO)	1.19	2.05
Sulphur Oxide (SO_3)	2.10	2.9
Potassium Oxide (K_2O)	0.13	0.73
L.O.I	2.70	1.20
Moisture Content	3.76	1.05

3.3: Setting Time Test

As it can be observed in table 3, the time required for CW/OPC past to harden increase with increase in CW replacement for both the initial and final setting times. This shows that CW has increase influence on OPC setting times.

Table 3: Results of Setting Times Tests of OPC/CW Pastes

% of CW	**Cement (g)**	**CW (g)**	**Water (ml)**	**Initial Setting Time (hrs.)**	**Final Setting Time (hrs.)**
0	800	0	120	1.30	5.10
5	380	20	130	2.25	6.30
10	360	40	134	2.50	6.55
15	340	60	152	3.00	7.10
20	320	80	174	3.20	7.30

3.4: Soundness Test

The expansion of CW specimen was less than 10 mm specified by BS 12:2: 1971. This confirmed that the CW is a good additive material. It was also clear that increase in CW content lead to increase in soundness of the pastes. For OPC without CW, the expansion was 1.3 mm. With increase in CW content there is an increase in soundness up to 15% replacement. At 20%, there was no further increase in soundness.

Table 4: Results of Soundness Test of CW/OPC Concrete

CW Content (%)	**Sample A (mm)**	**Sample B (mm)**	**Average Value (mm)**
0	1.3	1.3	1.3
5	1.3	1.5	1.4
10	1.6	1.6	1.6
15	1.8	1.8	1.8
20	1.6	2.0	1.8

3.5: Workability Test

The result of workability test using slump test method shows that the slump was within the range of 4-8 mm, this shows that the degree of workability was low. (ASTM 1881: Part 2:1970).The result of the compacting factor test on the sample also indicates low workability (Shetty, 2005).The compacting factor test on the samples fall between the range of 0.85 – 0.92 recommended by Neville and Brooks (2002) for roads and slabs concretes.

Table 5: Result of Workability Test for CW Concrete

CW	**W/c Ratio**	**Degree of Workability**			
		Slump (mm)		**Compacting Factor**	
0	0.65	8	Low	0.85	Low
5	0.65	7	Low	0.86	Low
10	0.65	6	Low	0.86	Low
15	0.65	6	Low	0.87	Low
20	0.65	4	Low	0.88	Low

3.6: Compressive Strength Tests

Table 6: 28 Days Compressive Strength of Specimens in Ordinary Water

Carbide Waste Content (%)	**Water Cement Ratio**	**28 Days Compressive Strength (N/mm^2)**			**Average**
0	0.65	25.58	25.62	25.60	25.60
5	0.65	22.10	23.00	22.32	22.47
10	0.65	24.42	24.60	24.86	24.63
15	0.65	19.46	20.80	20.22	20.19
20	0.65	16.42	18.92	18.46	17.93

The results of the compressive strength of concrete cubes as partial replacement of CW between 5 to 15% complied with BS 8110(1985) which states that the minimum compressive strength required for concrete to be used for structural purpose at 28 days should be between 20 -40N/mm.^{2}

3.7: Specimens Compressive Strength at Varying Temperatures

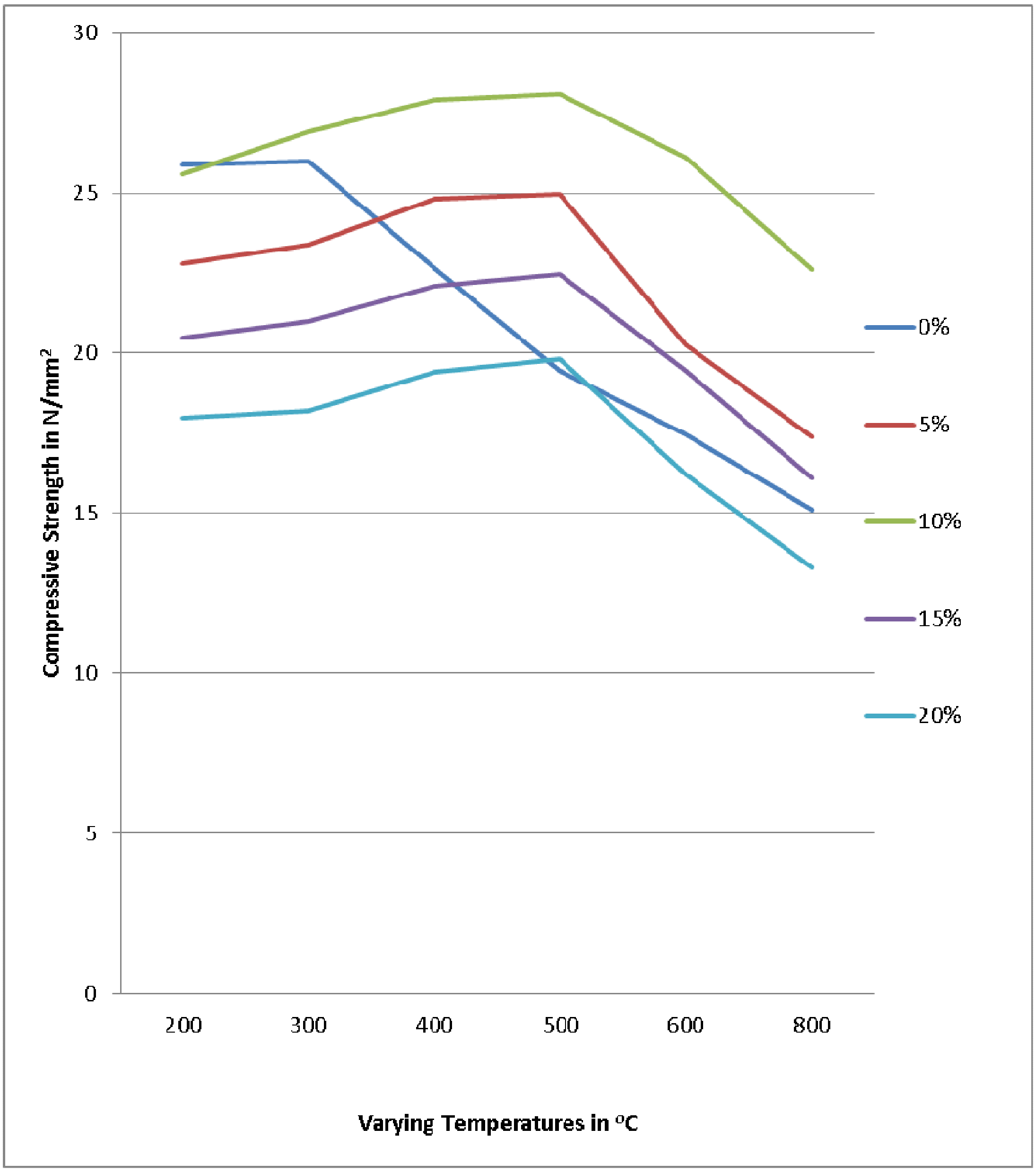

Figure 1: Line Graph of Specimen Compressive Strength at Varying Temperatures

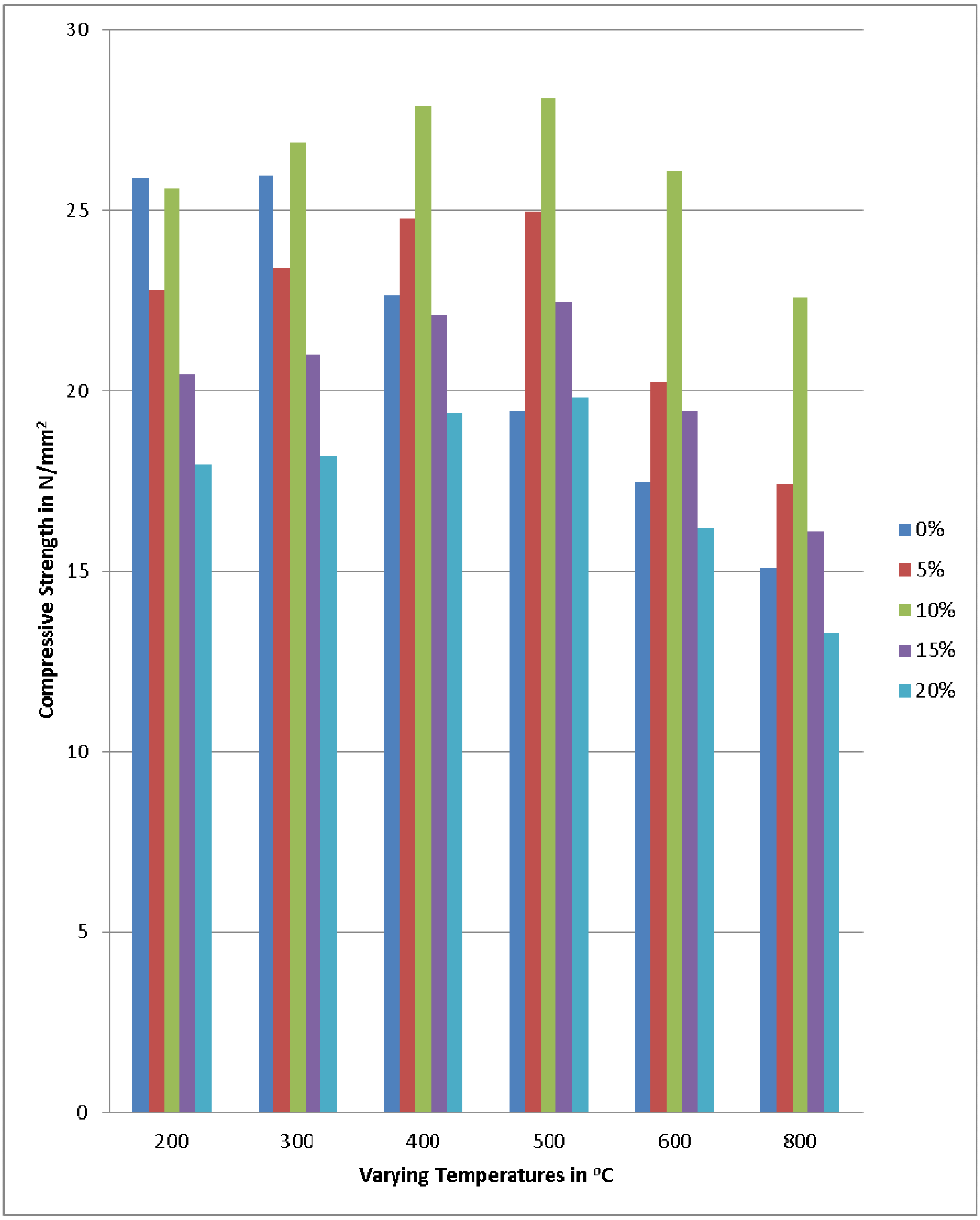

Figure 2: Bar Graph of Specimens Compressive Strength at Varying Temperatures

Figure 1 and 2 illustrate the typical development of compressive strength for the control and blended cement concretes thermally treated at 200, 300, 400, 600, 500 and 800^{o}C for 2 hours. It was observed that the compressive strength of control specimen increased with temperature up to 300^{o}C and then decrease up to 800^{o}C. It was also observed that the compressive strength of blended cement concrete (CW concrete) increase as the treatment temperature increased up to 500^{o}C then decrease as the temperature increased up to 800^{o}C. The increase in compressive strength in the control specimen up to 300^{o}C may be due to the additional hydration of un hydrated cement grains as a result of steam effect under the condition of so called internal autoclaving effect (Neville and Brooks 2002). The increase in compressive strength of the blended cement concrete specimens up to 500^{o}C may be due to the reaction of the admixture (CW) with the free lime to produce more CSH and CAH which deposit in the pore system. The compressive strength of the control started to decrease at 300^{o}C whereas those of the blended cement started to decrease at 500^{o}C. This phenomenon is contributed to higher volume of CSH and CAH phases formed in the blended cement concrete on one hand and reduction in $Ca(OH)_2$ contents on the other hand relative to those developed in control specimen. Cement matrix with higher volume of gel-like hydration products, and lower crystal-like $Ca(OH)_2$ contents has improved fire resistance (Neville and Brooks, 2002). The decrease in compressive strength with temperature may be due to the dehydration of $Ca(OH)_2$ at about 600^{o}C producing CaO and H_2O. Over 700^{o}C strength loss are mainly caused by calcium carbonate dissociation and subsequent CO_2 escaped from $CaCO_3$. Strength losses are less in blended cement concrete in comparison to the control. This is contributed to lesser $Ca(OH)_2$ contents found in blended cement concrete because of the admixture reaction consuming free lime disposable for $Ca(OH)_2$ formation, and hence for easy carbonation to $CaCO_3$ (Shetty, 2005).

4 Conclusions and Recommendations

4.1 Conclusions

Based on the test conducted, the following conclusions were drawn:

i) That the Carbide Waste (CW) performs satisfactorily as concrete fire resistance if the proportion of the CW is kept at 10 % replacement.
ii) The compressive strength of CW concrete compares favorably with that of control in ordinary water at 28 days.
iii) Soundness of cement increase as CW content increase.
iv) CW has increase influence on both initial and final setting time of OPC concrete, the setting times increase with increase in % of CW.
v) Replacing OPC with 10% of CW would increase the fire resistance of concrete by 14% to that of OPC concrete at 500^{o}C.

4.2 Recommendations

i) Further tests should be carried out on tensile and flexural strengths of CW concrete.
ii) In order to obtain the best result from CW as partial replacement of cement in concrete production, the CW content should be accurately measured which should be 10% of the cement used.
iv) Appropriate sieving of CW should be done after grinding in order to guide against impurities in the mix.
v) Further study should be carried out on the performance of CW concrete in other aggressive environments such as chemicals and hash weather.

5 Acknowledgements

The authors gratefully appreciate the assistance of all technologists in the Civil laboratory of Waziri Umaru Federal Polytechnic Kebbi State, Nigeria.

REFERENCES

Abalaka A. I. (2007): Properties of Bricks Stabilized With Carbide Waste: *Nigeria Journal of Construction Technology and Management,* Vol. 4. Pp. 12-19. University of Jos, Nigeria.

American Standard for Testing Materials ASTM C 494, "Standard Specification for Chemical Admixtures for Concrete."

American Standard for Testing Materials ASTM C 260: Specification for different types of concrete admixtures.

Arioz O. (2007) "Effect of Elevated Temperature on Properties of Concrete," Fire Safety Journal, Pp. 516-522.

British Standard Institution BS 1881: Part 2 (1970) Method for Determination of Slump, Her Majesty's Stationary Office: London, United Kingdom.

British Standard Institution BS 1881: Part 124 (1988) Methods of Analysis of Hardened Concrete. Her Majesty's Stationary Office: London, United Kingdom.

British Standard Institution BS 8110 (1985): Structural Use of Concrete: Code of Practice for Reinforced Concrete Structure, Her Majesty's Stationary Office: London, United Kingdom.

British Standard Institution BS 4550: (1978) Methods of Testing Cement: Her Majesty's Stationary Office: London, United Kingdom.

Dauda M. M.(2006): Properties of concrete produced with Carbide Waste: *Unpublished B.Sc. Project,* Ahmadu Bello University Zaria.

Demirboga R., Turkmen I. and Karakoc M. B (2007): "Thermo-Mechanical Properties of Concrete Containing High Volume Mineral Admixtures," *Building and Environment,* Pp. 349-354

Foldvari M., (1997): "Kaolinite-Genetic and Thermoanalytical Parameters.," J. *Thermal Anal. Calorimeter*, Pp. 107–119.

Neville, A.M. (1996): Properties of Concrete. *Longman Ltd*: United Kingdom. Pp. 1-5.

Neville, A.M. and Brooks, J.J. (2002): Concrete Technology. Longman Ltd, Essex, United Kingdom Pp.3

Morsy M.S., Rashad A. M. and El-Nouhy H. A. (2009): "Effect of elevated temperature on Physico-Mechanical Properties of Metakaolin Blended Cement Mortar," *Structural Engineering and Mechanics*, 31 (2009), Pp. 1-10

Shetty, M.S. (2005): *Concrete Technology Theory and Practice*. S. Chan and Company Publishers: Ram Niger, New Delhi.

Tan Z.(2012): "Concrete made Slag Improve Resistance to Fire Damage," *Cement Science Institute,* Pp. 161-193.

Xiaoa J. and Falknerb H. (2006): "Study On residual Strength of High-Performance Concrete With and Without Polypropylene Fibers at Elevated Temperatures," *Fire Safety Journal*, Pp. 115–121.